Mechanical Properties of Ultra-High Strength Fiber Reinforced Concrete M80-M150 Made with Indian Materials with Ambient Curing Regime

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Abstract. Study aims to design ultra-high strength fiber reinforced concrete with locally available Indian materials with ambient curing conditions, the study also aim to replace the binder with supplementary cementitious materials like ultra fine GGBS a waste material from the steel industry. UHSFRC mixes have been designed for the grades of M-80/ M-90/ M-100/ M-110/ M120/ M-130/ M-140/ M-150 at very low water to binder ratios. The water to binder ratio followed in the design are 0.14–0.20. Trials have been performed, cubes, cylinders and prisms are casted and checked for its mechanical properties like young's modules, splitting tensile strength, flexural strength and compressive strength of UHSFRC. The study has been concluded that locally obtained Indian materials are perfectly suitable to develop UHSFRC at site curing conditions. The natural sand can be replaced 100% with quartz sand, binder can be replaced up to 30% with UFGGBS. The maximum compression strength results reached to 164.4 N/mm^2, flexural strength reached to 23.87 N/mm^2, the maximum splitting tensile strength achieved 9.76 N/mm^2 and Youngs Modules achieved 77,080 N/mm^2 for M150 with normal curing conditions at 27 °C + / −2, this concrete is economical, highly durable and sustainable.

Keywords: UHSFRC · UHPC Pri-Mix · Crimped Steel Fibers · SCM · Thermal Curing

1 Introduction

The normal concrete will be designed based on compression strength which will serv very few practical challenges. the ultra-high strength fiber reinforced concrete (UHSFRC) is the great innovation in advanced concrete technology. UHSFRC is highly workable, higher young's modulus, higher density matrix, higher stability with least dimensions of the structural member, very low water penetration with higher resistance to chemicals. significant reduction of water to cement ratio in concrete is the fundamental step for making UHSFRC. reduction in water to binder ratio lower than 0.20 with higher density matrix by using aggregate size lower than 4.75 mm will improve the properties of

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UHSFRC, UHPC pri-mixes are available in the international markets at higher prices, these pri-mixes needs thermal curing at higher temperatures to speed up the hydration process. Liew J.Y.R., *et. al.,* (2020) [1] has made UHPC by adding the water with a commercially available pre-mix of UHPC available in the European markets. In this study we are designing a UHSC mix with locally available materials without using any pre blend market mix. Edwin Paul Sidodikromo, *et. al.,* (2019) [2] concluded that UHSC at high-temperature curing results in 30–37% growth of the compressive strength. In the present study we have opted for normal curing regime at 27 °C ±2 °C as it is easily available with cheaper cost at site. Tiefeng Chen *et. al.,* (2018) [3] made a study on compressive strength and flexural behavior of UHPC. The mix was designed with supplementary cementitious material like silica fume and fly-ash at different quantities at 0%–30% with autoclave curing process. In the present study cement has been partially replaced with ultra-fine ground granulated blast furnaces slag at maximum 30% by weight of cement. Jayesh S. Gosavi, U. R. Awari *et. al.,* (2018) [4] concluded that finer materials make concrete denser, which result the concrete resistant against water, chemical, moisture and carbon dioxide. supplementary cementitious material like silica fume, GGBS, fly-ash will make the concrete denser. silica fume 5%, GGBS 30% and fly-ash 30% replacement levels will improve the properties of concrete. but fly-ash may be fever to carbonation of concrete, In the present study ultra-fine ground granulated blast furnaces slag has been partially replaced with cement, as ultra-fine ground granulated blast furnaces slag is a super fine material which improve the packing density, long-term strength and durability of UHSFRC.

2 Materials

The materials that are used for the experimental investigation are listed below:

1) Ordinary Portland cement of Grade 53 conforming to IS: 269
2) Ultrafine Ground Granulated Blast Furnace Slag
3) Natural Sand
4) Quartz Sand (2.37mm/ 1.18mm)
5) High end water reducing agent (High PC)
6) Crimped Steel fibers
7) Water

2.1 Physical and Chemical Properties of Materials

Cement: In this study Ordinary Portland Cement of Grade 53 conforming to IS 269.2015 has been used. 53 Grade OPC provides high strength and durability to structures because of its optimum particle size distribution and superior crystallized structure. Blended cements can also give superior results, but these cements will be containing pre-designed cementitious materials like fly-ash or GGBS by which it is not possible to redesign the total cementitious content in the UHSC mix design. Hence Ordinary Portland cement has been chosen for the design of UHSC concrete mix. Following are the Physical properties of cement in Table 1.

Ultra-Fine GGBS: It is the by product from the steel manufacturing industry and it is a promising material which can be considered as secondary binding material as its

Table 1. Physical Properties of OPC-53 Cement

S No	Properties	Results	As per IS 269-2015
1	Specific Gravity	3.14	3.15
2	Specific Surface Area	310 (m2/kg)	Not less than 225(m2/kg)
3	Soundness	0.75mm	Not less than 10mm
4	Normal Consistency	28%	--
5	Initial setting time	110 minutes	Not less than 30 minutes
6	Final setting time	280 minutes	Not more than 600 minutes
7	Compressive Strength 28 Days	61 MPa	Not less than 53 MPa

Table 2. Chemical Properties of Ultra-Fine GGBS

S No	Constituents	Composition (wt.%)
1	Iron Oxide (Fe_2O_3)	1.2
2	Sulphur Trioxide (SO_3)	0.13
3	Silica (SiO_2)	35.3
4	Magnesia (MgO)	8.2
5	CaO	33.77
6	Alumina (Al_2O_3)	21.4

Table 3. Physical Properties of Ultra-Fine GGBS

S No	Property	Results	
1	Specific Gravity	2.7	
2	Bulk Density	680 kg/m^3	
3	Specific Surface Area	12000 cm^2/gm	
4	Particle Size Distribution in Micrometers	d10	1.8
		d50	4.4
		d90	8.9

chemical composition matches with cement. due to its higher fineness helps in filling up of pores in concrete resulting in better strength improvement and resistance to permeability action in concrete. Tables 2 and 3 contains a detailed chemical and physical properties of ultra-fine GGBS.

Natural Sand: Sand which is obtained from the riverbed is used as Fine Aggregate. Natural Sand is used in the form of Saturated Surface dry state. From mix M80-M150 natural sand replaced in different replacement levels, in the final mix M150 – 100%

Table 4. Physical Properties of Natural Sand

S No	Property	Value
1	Specific Gravity	2.66
2	Fineness Modulus	2.72
3	Zone	II

Table 5. Physical Properties of Quartz Sand

S No	Property	Quartz sand(Q1)	Quartz sand(Q2)	Quartz sand(Q3)
1	Particle Size	4.75–2.26 mm	2.36–1.18 mm	1.18mm–600μ
2	Moisture Content	1.40%	1.40%	1.40%
3	Fineness Modulus	2.64	2.61	2.56
4	Specific Gravity	2.6	2.6	2.6
5	Gradation	Zone I	Zone I	Zone I

natural sand has been replaced with quartz sand of 2 sizes. Table 4 contains properties of natural sand.

Quartz Sand: Quartz sand contains SiO2. It's a hard material and chemically inert. on Moh's hardness index it is grades 7 out of 10. This sand is ideal for filtration bends in water purification segment. Quartz sand physical properties are given in Table 5.

HRWRA: Super plasticizers plays a vital role in high strength concrete design, in this study Normet-TemCem 53-V has been used to deal the mix at water cement ratios ranges from 0.13–0.20, This admixture can reduce up to 40% water demand in the design mix of UHSC. Table 6 contains detailed properties of HRWRA.

Crimped steel fibers: These are low carbon, cold drawn steel wire fibers which helps to reduce shrinkage cracking intensity, enhanced flexural behavior, improved shear strength and improves most of the mechanical properties of UHSC. Crimped steel fibers performance will be superior when compared with normal steel fibers. Properties are elaborated in Table 7.

3 Mix Design of Ultra-High Strength Fiber Reinforced Concrete—M80/M90/M100/M110/M120/M130/M140/M150

Pan mixer is suitable for UHSFRC mixing. dry ingredients like cement/ UFGGBS/ silica sand has to place in pan mixer and need to mix it in dry condition for about 3 minutes. after the mixing of materials at dry condition water need to be added slowly. Once the half quantity of water addition, admixture need to be added in the mix very slowly by observing the behavior of the mix, additional mixing is to be performed at this speed until a uniform mixture achieves proper workability. in the last stage steel fibers need to be added to the mix slowly till flowable consistency was achieved. Need to make the

Table 6. Properties of High-End Water Reducing Agent

S No	Property	Result	QC limits – (As per IS 9103)
1	Physical State and Color	Brown color free flowing liquid	–
2	Active Constituent	Organic Hydroxycarboxylic acid	–
3	Relative Density @ 250C	1.12	1.12 ± 0.02
4	pH	7	Min. 6
5	Dry Material Content	42.45%	42 ± 5%
6	Chloride Ion Content	0.01%	Max 0.2%

Table 7. Physical Properties of Crimped Steel Fibers

S No	Property	Value
1	Length	30.8 mm
2	Diameter	0.73 mm
3	Aspect Ratio (l/d)	42.3
4	Density kg/m^3	7800
5	Fiber Intrinsic Efficiency Ratio	169.4
6	Ultimate Tensile Strength	1.85 GPa

casting for cubes/ prisms and cylinders. after 24 hour place the specimens in the curing tank at normal temperature (Figs. 1, 2, 3 and 4; Table 8).

Fig. 1. UHSC Constituents

Fig. 2. UHSFRC Making in Pan Mixer

Fig. 3. UHSFRC Specimens

Fig. 4. Testing of Cubes, Cylinders, Prisms for its Mechanical Properties

4 Results and Discussions

The 28-day strength of concrete cubes of 100mm x 100mm x 100mm has been found on compression testing machine of 5000 kN, Cylinders has been tested for its splitting tensile strength and young's modulus, Prisms has been tested on UTM for its flexural strength. Table 9 contains detailed results of concrete mix wise from M80-M150 (Figs. 5, 6, 7 and 8).

Table 8. UHSFRC Mix Design

S No	Grade of Concrete	Cement Kg/m^3	UF. GGBS Kg/m^3	N Sand Kg/m^3	Q Sand - F - Kg/m^3	Q Sand - M - Kg/m^3	Q Sand - C - Kg/m^3	Water - Kg/m^3	W/C Ratio	S Fibers Kg/m^3	% Steel Fibers	HRWRA Kg/m^3
1	M80	685	200	675	-	180	-	175	0.2	112	1.44	10.5
2	M90	720	230	1020	-	210	-	175	0.18	120	1.54	11.49
3	M100	1040	310	-	800	-	-	187.2	0.14	147.8	1.89	8.1
4	M110	1040	320		450	450	-	187.2	0.14	189.2	2.43	8.5
5	M120	1050	330	-	-	800	-	180	0.13	165	2.12	8.1
6	M130	1115	368	-	-	800	-	228	0.15	161	2.06	8.3
7	M140	1120	375	-	-	600	200	235	0.16	162	2.08	8
8	M150	1107	344	-	-	400	400	232	0.16	163	2.09	13

Table 9. Mechanical Properties of UHSFRC M-80 to M150

S No	UHSC Mix	Compressive Strength		Flexural Strength		Young's Modulus		Splitting Tensile Strength	
		Range N/mm^2	Result (N/mm^2)	Range= 0.7√Fck (N/mm^2)	Result N/mm^2	Range = E = 5000 √Fck	Result (N/mm^2)	Range = 0.398(√fck) (N/mm^2)	Result (N/mm^2)
1	M80	89.17	90.03	6.26	13.41	44721.35	55392	3.56	5.31
2	M90	99.65	103.51	6.64	13.65	47434.16	57418	3.78	5.92
3	M100	110.09	112.01	7.01	14.91	50000	59725	3.98	6.63
4	M110	120.32	122.61	7.34	17.25	52440.44	62430	4.17	7.27
5	M120	130.46	131.66	7.67	20.23	54772.25	67422	4.36	7.85
6	M130	141.1	142.09	7.98	21.32	57008.77	70625	4.54	8.52
7	M140	151.92	153.01	8.28	22.91	59160.79	73092	4.71	9.03
8	M150	162.9	164.04	8.57	23.87	61237.24	77080	4.87	9.76

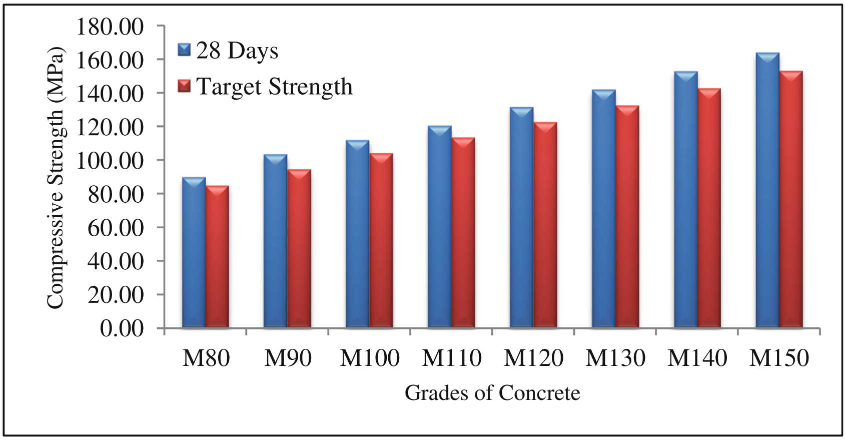

Fig. 5. Actual 28 Day Compressive Strength Vs Target Mean Strength

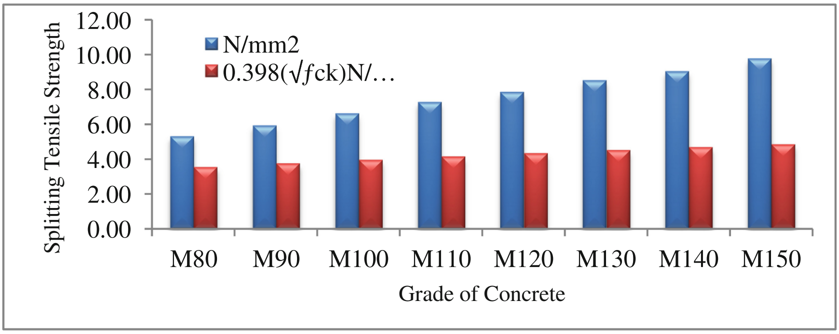

Fig. 6. Actual Splitting tensile strength of Cylinders at 28 Days Vs Theoretical

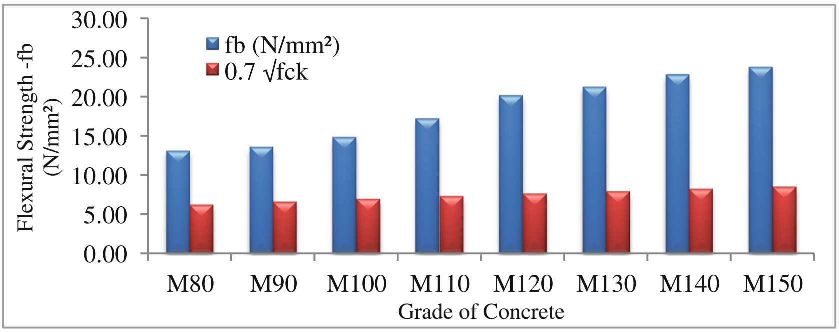

Fig. 7. Actual Flexural Strength of Prism at 28 Days Vs Theoretical

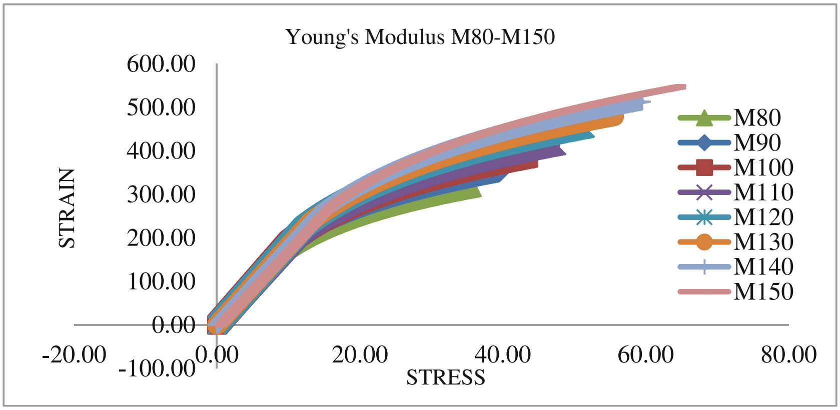

Fig. 8. Young's Modulus M80-M150

5 Conclusions

Based on the mixes developed for Ultra-High strength fiber Reinforced Concrete it is concluded as follows:

- Quartz sand of medium and courser size is perfectly suitable at replacement level of 100% with natural sand. This will make a durable and sustainable concrete without any environmental impact.
- Water cement ratios plays a key role in the design of UHSFRC from M80-M150. By reducing water cement ratios below 0.20 the higher strengths can be achieved.
- In the design of UHSFRC cement can be reduced by replacing more quantity of mineral admixtures which results in low carbon footprints. In this study Ultra-Fine GGBS shown superior performance when it is replaced with cement up to 30%.
- Crimped steel fibers reduce the shrinkage and plays a good role in improving the mechanical properties of UHSFRC, especially flexural strength of UHSFRC.
- High end water reducers play a key role in low water cement ratio mix designs; In this experimental work it is found that High PC admixtures effectively works in the design of UHSFRC.
- The UHSFRC Designs obtained in this research have gained desired mechanical properties with site curing conditions. The same design specimens can gain higher mechanical properties if it undergoes Heat Curing process. As Heat curing improves the hydration process in concrete matrix comparing the site curing, but site curing is easy and economical, Heat curing is costly.

Hence it is concluded that Local Materials are perfectly suitable for the design of Ultra-High strength fiber reinforced concrete by which we can reduce the cost of UHSC when comparing with readily available pre-mixes of UHSC.

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